STUDY OF PROPERTIES OF FLEXIBLE ARTIFICIAL DIELECTRIC

S. S. GUPTA AND M. N. SHARMA

DEPARTMENT OF PHYSICS, UNIVERSITY OF LUCKNOW, LUCKNOW

(*Received August 8, 1964*)

ABSTRACT. Flexible artificial dielectrics have been constructed by embedding metal powders in polythelene. The dielectric constants and loss tangents of these dielectrics have been determined experimentally at radio frequency (10.75 MC/s). Variation of the modulus of elasticity with percentage of metal particles of the metal embedded media have been studied. Results show that there is a simple relationship between modulus of elasticity and the dielectric constant. These flexible dielectrics may prove more advantageous than those constructed by embedding microscopic conducting particles in wax, due to formers mechanical properties, moulding ease and the wide temperature range within which they can be used.

INTRODUCTION

There are two well known types of artificial dielectrics, one consists of an array of wave guides and the second one comprises of a cubic lattice of conducting particles having a size and separation small compared with the wave length. Such a medium was proposed by Kapzov as early as 1922 and Kock (1948) gave it a practical form. Carruthers (1951) later on proposed a dielectric medium, suitable for very short wavelengths, consisting of light weight medium embedded with some fine metal powder. Kelly and coworkers (1953) measured the dielectric properties of metal powders in paraffin wax using the microwave technique. Same type of work has been reported by Negebauer (1952), Peppiatt (1953), Mayer *et al.* (1956) and Mickaelion (1955). The dielectric properties of such media are affected by (a) volume fraction of conducting particles (b) size and shape of metal particles and (c) binding medium. Recently Pradhan and Gupta (1961) have shown that it also depends on the elemental spacing distribution of particles.

Most of the workers used paraffin wax as binding medium due to ease with which it could be handled, but we have used polyethelene as binding medium in the construction of flexible artificial dielectrics, although polythelene is tough in handling but is more advantageous due to its mechanical properties, ease in moulding, resistance to moisture and the wide temperature range within which it can be used.

EXPERIMENTAL PROCEDURE

Preparation of samples : Polyethelene granules ($\epsilon = 2.3$, $\tan\delta = 0.001\times10^{-4}$, density, $d = 0.91$ gm/mL and modulus of elasticity, $E = 9.83\times10^{8}$ dynes/cm^2) and metal powder each were weighed in calculated quantity for a particular sample, The mixture of polyethelene granules and metal powder was put in a air tight vessel, having a mechanical mixing arrangement. The vessel was heated in a temperature regulated electrical oven for about 30 minutes, keeping the temperature of oven at about 110°C. This process melted the polyethelene. The molten mixture was continuously stirred and then it was cooled till it solidified. The solid mass was removed with a scraper, the scraped mass was dessicated for 36 hours and then was moulded under compression in a hot brass cast in the form of disc. These moulded samples were grinded and polished.

Procedure : The method of Hartshorn and Ward (1936), for the measurement of dielectric constant and loss tangent at radio frequencies was used. The dielectric constant and loss tangent of different samples were determined at 10.75 MC/S as described in detail by Sharma (1960), Pradhan and Sharma (1960) and Sharma and Gupta (1962).

The dielectric constant K of a solid sample is given by

$$K = 3.6C_s t \quad (1)$$

where C_s is capacitance of the sample in $\mu\mu F$, t the thickness of the sample and r is the radius of the electrodes (2.5 Cms).

The loss tangent is given by

$$\tan \delta = \frac{\Delta C_1 - \Delta C_0}{2C_s} \quad \ldots \quad (2)$$

where ΔC_1 is capacitance change corresponding to half of the maximum deflection with sample in between the two copper electrodes and ΔC_0 is the capacitance change corresponding to half of the maximum deflection without the sample.

The modulii of elasticity of various samples were determined as follows :

The scraped mixture of polyethelene and conducting particles used for dielectric samples was moulded in the form of thin rods having circular cross-section (about 10 Cms. long and 1 mm. thick). One end of the rod was clamped to a rigid support and at the other end of the rod the stress was applied. The lengths between the two clamps, radius and elongation of each sample were measured with a travelling microscope having a least count of 0.0001 Cm. Thus, knowing stress and strain, elastic modulii for different samples were calculated.

RESULTS AND DISCUSSION

Experimental determination of dielectric K_s, and loss tangent for different metal powder artificial dielectrics has been carried out at 10.75 MC/S. for different concentrations of metal powders. Values are given in Tables I and II. Variation of dielectric constant K_s and loss tangent for aluminium, copper, anitmony and zinc with concentration are shown in Figs. 1 and 2 respectively.

Microscopic examination of particle used, showed that aluminium particles ($9\mu \times 7\mu \times 8\mu$) were in the shape of the discs, copper ($18\mu \times 10\mu \times 9\mu$) and antimony

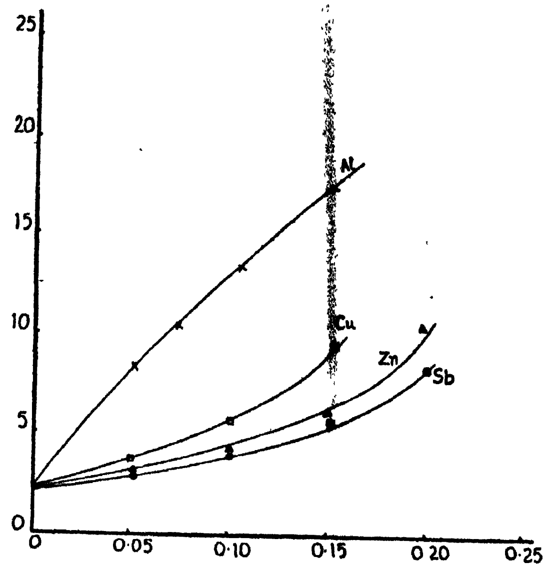

Fig. 1. Variation of dielectric constant with volume fraction.

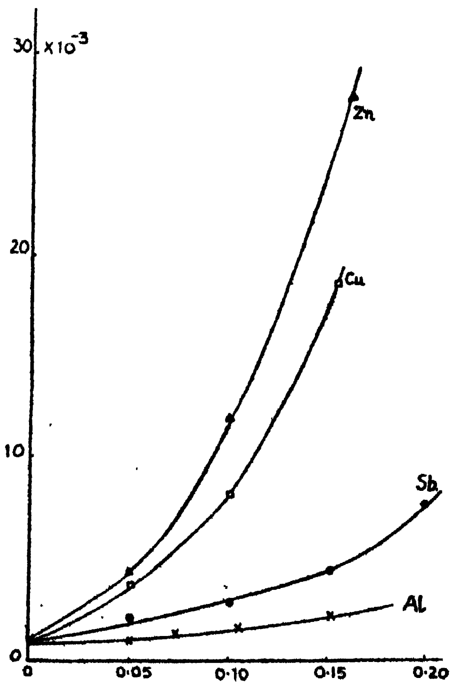

Fig. 2. Variation of loss tangent of metal powder artificial dielectrics with volume fraction.

($5\mu \times 4\mu \times 2\mu$) particles were irregular in form while zinc (5μ in diameter) particles were more or less spherical. From theoretical considerations, it may be noted that for the same volume fraction of conducting particles, aluminium dielectrics should have highest dielectric constant while copper dielectrics should have dielectric constant higher than those of antimony and zinc. For the last two materials, i.e., for antimony and zinc, the antimony dielectrics should have higher dielectric constant. Experimental results verify expectations for aluminium and copper dielectrics but in case of antimony and zinc dielectrics the case is just reversed.

On calculating α_e/ϵ_0, for aluminium, zinc and antimony mixtures from the Clausius-Mossotti relation

$$\frac{K_e-K}{K_e+K}=\frac{N}{3}(\alpha_e/\epsilon_0) \tag{3}$$

and plotting it against the fractional volume of conducting particles (Fig. 3),

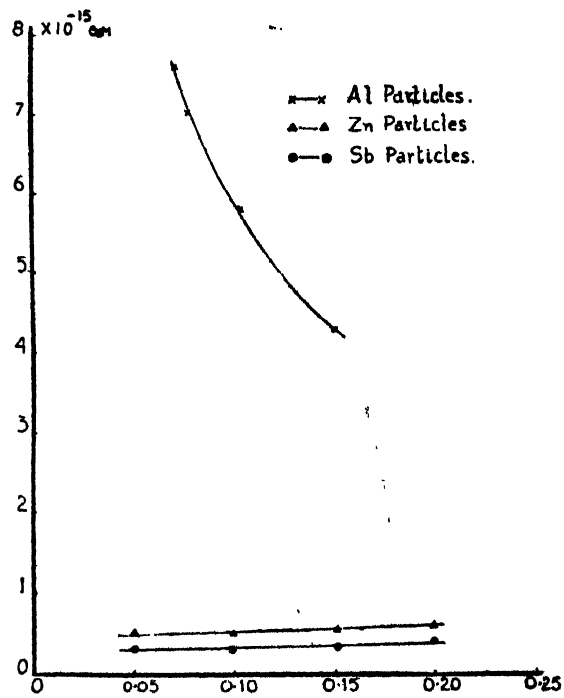

Fig. 3. Variation of polarizability with fractional volume of particles.

we observe that the polarizability in case of aluminium particles decreases with increasing concentration which may be attributed to change in shape of aluminium disc particles to ellipsoidal form. For zinc particles the polarizability increases with concentration, showing that particle shape is altered due to agglomeration of particles. The distribution of particles is also such that there is considerable interaction between the particles. The resulting curve of polarizability for antimony particles is horizontal, pointing out that the polarizability remains constant with variation in volume fraction, although it should have increased due to agglomeration. This indicates that either there is no agglomeration or there is no interaction between the particles.

Let us consider the case of copper, antimony and zinc dielectrics, i.e., which are constructed by embedding particles of heavier metals. For the same volume fraction of conducting particles, the dielectric constant was highest for copper dielectrics and lowest for antimony dielectrics i.e. highest for the dielectric shaving

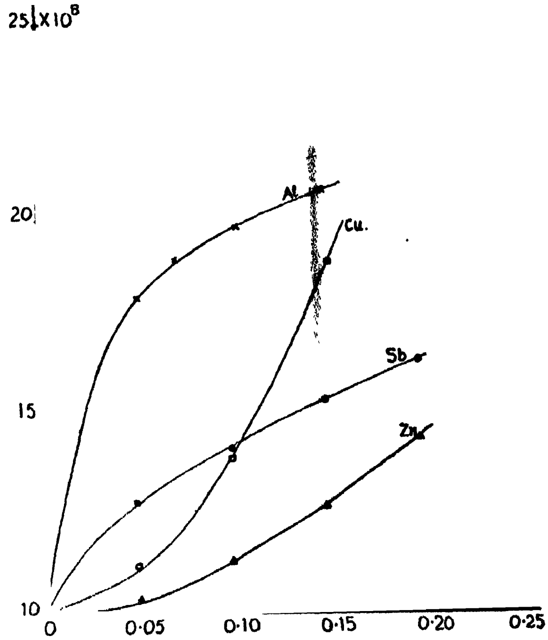

Fig. 4. Variation of modulus of elasticity with concentration of metal particles.

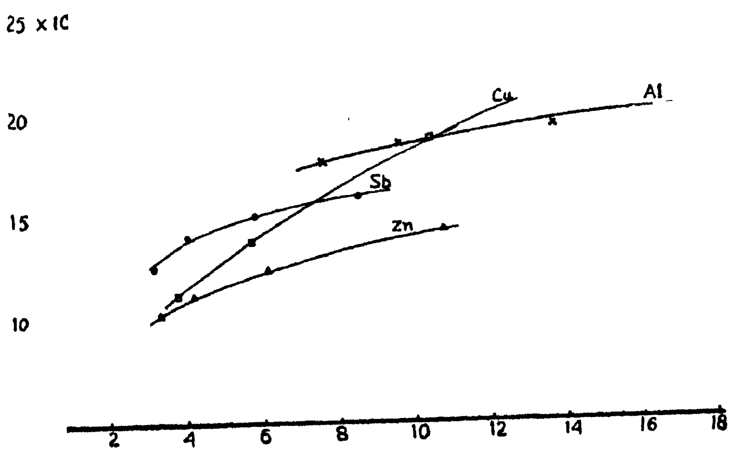

Fig. 5. Variation of mechanical strength of metal artificial dielectrics with dielectric constant.

particles of highest electrical conductivity and vice-versa. This indicates that the dielectric constant of artificial dielectric also depends on the electrical conductivity of the metallic particles used.

The variation of modulus of elasticity with concentration of conducting particles and with the dielectric constant are shown in Figs. 4 and 5. The curves show that a simple relationship exists between the modulus of elasticity and the dielectric constants of these artificial dielectrics.

Interesting results might be obtained if measurements on these flexible artificial dielectrics are extended to microwave region.

TABLE I

Variation of dielectric constant of metal powder artificial dielectrics with concentration.

Aluminium		Copper		Antimony		Zinc	
Fractional volume	K_e	Fractional volume	K_e	Fractional volume	K_e	Fractional volume	K_e
4.930	8.53	4.885	3.764	4.957	3.089	4.974	3.214
7.231	10.36	9.951	5.654	9.988	3.957	9.856	4.130
10.401	13.66	15.290	9.621	15.120	5.712	14.950	6.091
15.220	17.61	—	—	19.950	8.958	19.070	10.700

TABLE II

Variation of loss tangent of metal powder artificial dielectrics with concentration.

Aluminium		Copper		Antimony		Zinc	
Fractional volume	$\tan\delta\times10^4$	Fractional volume	$\tan\delta\times10^4$	Fractional volume	$\tan\delta\times10^4$	Fractional volume	$\tan\delta\times10^4$
4.930	10.32	4.885	38.05	4.957	22.31	4.974	42.30
7.231	14.94	9.951	80.28	9.988	26.80	9.856	119.10
10.401	15.54	15.290	189.50	15.120	44.31	14.950	283.60
15.220	23.12	—	—	19.950	79.29	19.070	733.00

ACKNOWLEDGMENT

Authors are indebted to Professor P. N. Sharma for his kind interest and encouragement. Authors are also grateful to Dr. B. P. Pradhan for supervision of the work.

REFERENCES

Carruthers, J. A., 1951, United States Air Force Contract No. AF 19(122)81, Eaton Electronic Research Laboratory Rep. No. 5.
Hartshorn, L. and Ward, W. H., 1936, *Proc. Inst. elect. Engrs.*, **79**, 597.
Kapzov, N., 1922, *Ann. Phys., Lpz.*, **69**, 112.
Kelly, J. M., Stenoien, J. O. and Isbell, D. E., 1953, *J. appl. Phys.*, **24**, 258.
Kock, W. E., 1948, *Bell. Syst. Tech. J.*, **27**, 58.
Meyer, E., Schmitt, H. J. and Severin, H. 1956., *Z. angew. Phys.*, **8**, 257.
Mikaelian, A. L., 1955, *Radiotekhnika.*, Moscow, **10**, 1.
Neugebauer, H. E. J., 1952, Air Force Contract No. AF19(122)81, Eaton Electronic Research Laboratory Rep. No. 6.
Peppiatt, H. J., 1953, United States Air Force Contract No. AF19(122)81, Cambridge Research Centre Rep. No. D6.
Pradhan, B. P. and Sharma, M. N., 1960, *Proc. Nat. Inst. Sci.*, **26** A, 560.
Pradhan, B. P. and Gupta, R. C. 1961, *J. Sci. industr. Res.* **20B**, 581.
Sharma, M. N., 1960, *J. sci. industr. Res.*, **19B**, 5.
Sharma, M. N. and Gupta, S.S. 1963, *Ind. J. Phys.*, **37**, 33.